Draper Laboratory's Capabilities for Space Based Laser

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Capabilities Applicable to SBLRD

- Pointing Control (ATP)
  - Inertial Pseudo Star Reference Unit (IPSRU)
  - Precision Pointing Test Facility
  - Enhanced Angle Sensor
- Inertial Sensors
  - Low Noise Third Generation Gyro (LNTGG)
  - Strategic Grade IFOG
- Active Vibration Isolation System (AVIS)
  - Broadband Isolation for large (100 inch) flexible telescope
- Beam Control
  - LODE - Beam pointing/jitter control system analysis
  - DEWATP - Pointing and wavefront control modeling & design
- Wavefront Control
  - LAMP - detailed analysis of wavefront control system
  - ABCS - Analysis and design of jitter and wavefront control system
- Integrated Structural/Optical Models and Design Tools
  - Modeling tool integrates NASTRAN, COMP(Optical Modeling), & SIMULINK
  - Custom MATLAB Controls Toolbox for Design & Real-Time Implementation

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Draper Lab Policies

- An independent, not-for-profit corporation dedicated to applied research, engineering development, education, and technology transfer
  - Focus on the design and development of first-of-a-kind systems
  - Does not compete with industry
  - Typically engages in contracts on a sole source CPFF basis

- Draper will team with prime contractors on a non-exclusive basis
  - Will protect proprietary information
  - Will develop independent, compartmentalized proposal teams if required
  - Teaming agreements will be required to protect the interests of both the Laboratory and the Prime Contractor

IPSRU Overview

- IPSRU is a Precision Pointing, Tracking and Jitter Stabilization Reference Unit
  - It outputs a collimated probe beam, a pseudo star from a two-degree-of-freedom inertially stabilized platform
  - The pseudo star serves as a master reference for jitter stabilizing imaging and weapon pointing systems
- The IPSRU system is also a self-contained 3-axis inertial attitude measurement system (2nd Gyro mounted on IPSRU base)
- A flight-worthy IPSRU system has been built by Draper Laboratory and was delivered (March 1994) to Phillips Laboratory for Integration into the High Altitude Balloon Experiment (HABE)
- IPSRU Measures Performance:
  - Beam Jitter — 34 nanoradians rms 0.1 - 300Hz
  - Base Motion Isolation — 110 dB at 0.1 Hz
    55 dB 1 to 100 Hz

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IPSRU Functional Schematic

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IPSRU Functional Capabilities

- Inertially Stabilized Reference Beam
  - Gyro and ADS information combined through blending filter to actively stabilize the IPSRU platform over a wide bandwidth
    - 34 nRad, 0.1-300Hz
- Spacecraft Inertial Attitude Reference
  - Platform gyro, base-to-platform position sensors, and base gyro measurements used to provide precise knowledge of base inertial attitude
    - Bias Drift < 4x10-3 deg/h
    - Resolution < 2.5 micro-rad
- Target Track and Slew Mode
  - Tracking sensor commands are fed to the IPSRU gyros to move the probe beam Los in inertial space to follow-target motion and/or point ahead as required
  - Output from IPSRU platform sensors is fed to S/C attitude controllers in a follow-up mode, 5°/s & 10°/s^2

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IPSRU Design Features

- Composite, wide-band, low-noise inertial sensing is provided by a dynamically-tuned two-degree-of-freedom gyro (DTG) and two Angular Displacement Sensors (ADS)
- A central hinge provides two axes of rotational freedom, rotational flexure spring rates are soft and the translational suspension is stiff
- Four linear force actuators and servo loops provide two axes of control
- A second gyro (DTG) mounted on the base provides the third axis of attitude information
- The optical light source wavelength (780 nm) is modular, easily changed
- System electronics are mounted on printed circuit boards and housed in a ruggedized VME ATR unit
- IPSRU has a dedicated processor and software for system control, calibration, compensation and attitude algorithm
- IPSRU has the flexibility to accommodate accelerometer data

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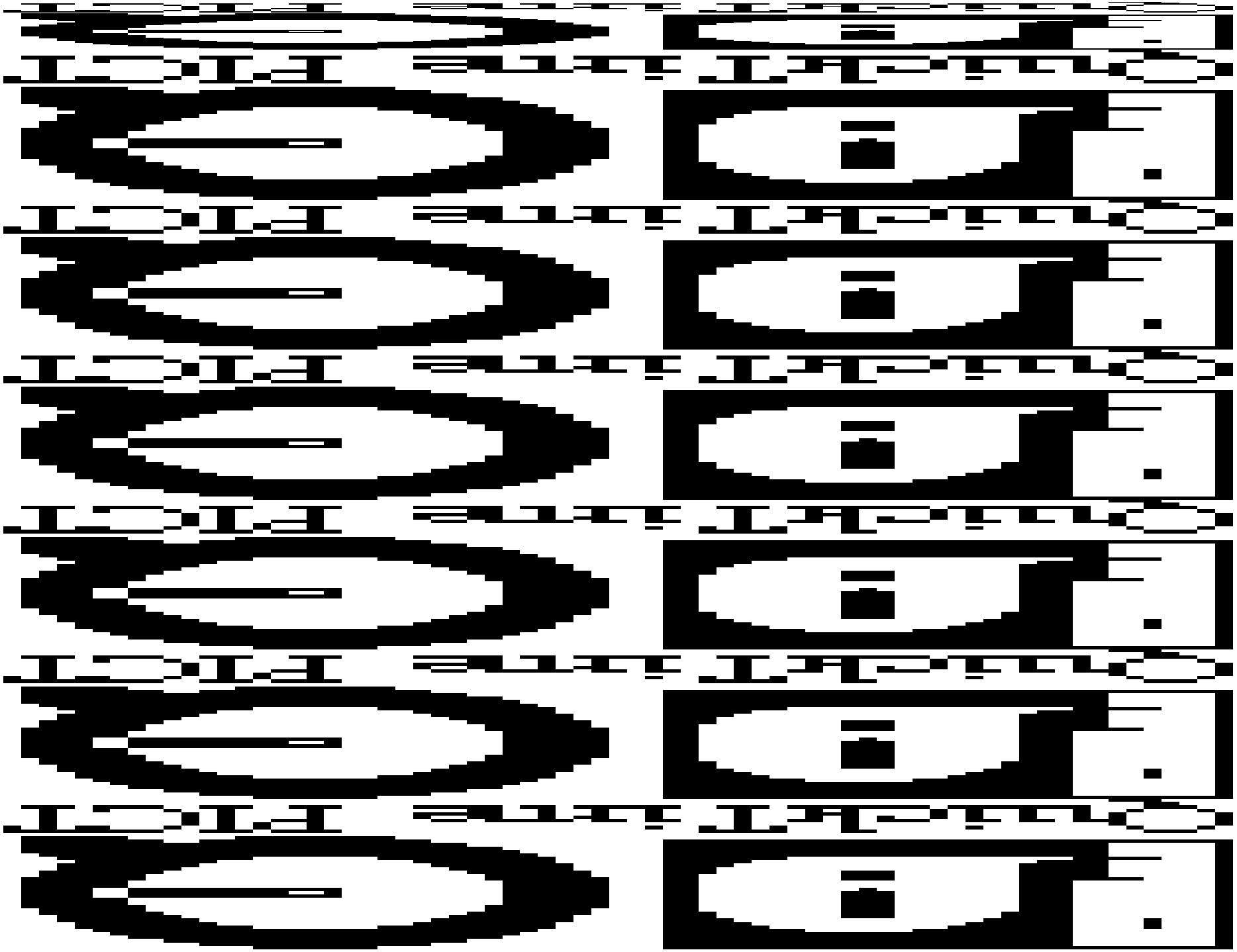

IPSRU Application Concept

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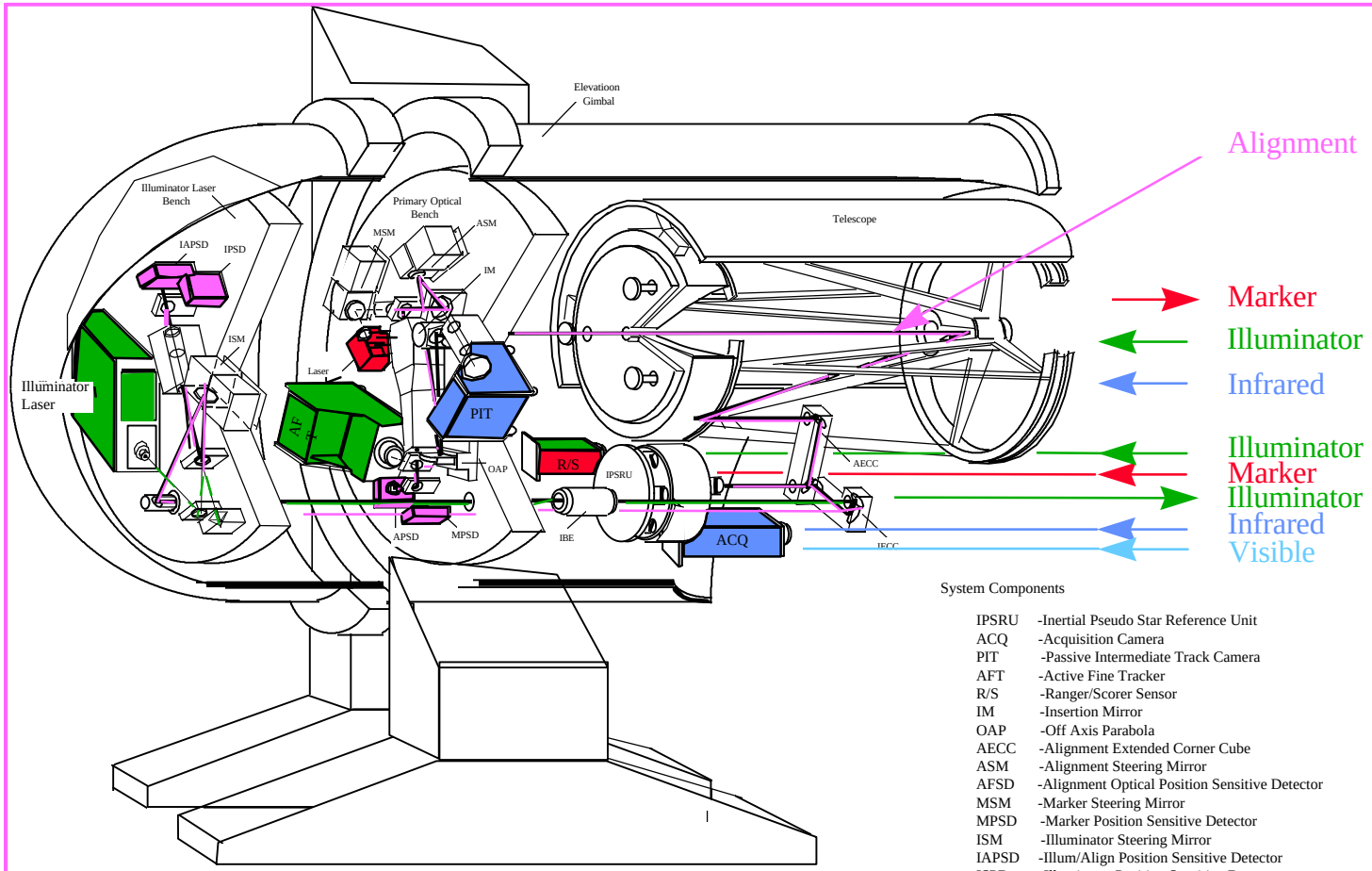
IPSRU Implementation In HABE
(Optical Canister Schematic)



System Components

IPSRU	-Inertial Pseudo Star Reference Unit
ACQ	-Acquisition Camera
PIT	-Passive Intermediate Track Camera
AFT	-Active Fine Tracker
R/S	-Ranger/Scorer Sensor
IM	-Insertion Mirror
OAP	-Off Axis Parabola
AECC	-Alignment Extended Corner Cube
ASM	-Alignment Steering Mirror
AFSD	-Alignment Optical Position Sensitive Detector
MSM	-Marker Steering Mirror
MPSD	-Marker Position Sensitive Detector
ISM	-Illuminator Steering Mirror
IAPSD	-Illum/Align Position Sensitive Detector
ISPD	-Illuminator Position Sensitive Detector
IBE	-Illuminator Beam Expander
ICC	-Illuminator Corner Cube
IECC	-Illuminator Extended Corner Cube

IPSRU Modifications for SBLRD

- Repackage Electronics Assembly for space application
  - Conduction cooled chassis
  - Current electronics are a space qualifiable design using 883 B parts
  - Space qualified replacements are available
  - Assessment of radiation issues
- Increase slew rate capability to 15 deg/s via electronic modifications
- Replace SCRAMNET I/O with applicable SBL system I/O
- Modify software to adapt to SBL system I/O and moding/calibration procedures
- Reconstitute test facilities
- Complete documentation of software and operations manual
- Retest and requalify system

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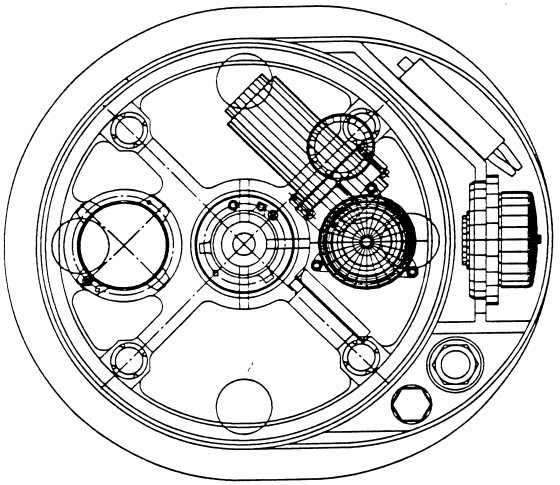
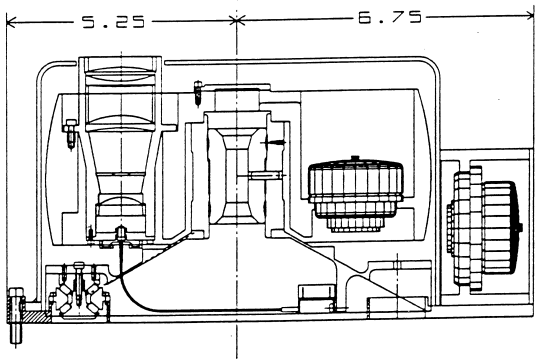
IPSRU Configuration

IPSRU Requirements*	Req / Results
• **Reference Stabilization**	
– Jitter (1-Axis RMS), nrad	100 / 39
– Base Motion Rej @ 1 Hz, dB	> 80 / 88
– Base Motion Rej (1-100 Hz),dB	> 40 / 45
– Angular Range, mrad	10 / 10
– Angular Rate, deg /sec	2 / 2*
– Angular Accel, deg/sec^2	1.15 / 1.15*
• **Attitude Knowledge**	
– Attitude Error, deg/hr	0.06 / 0.055
• **Optical**	
– Wavelength, nm	780 / 780
– Collimation, waves (P-V)	1/4 / 1/4
– Quality, waves (P-V)	1/13 / 1/13
– Laser Power, mW	6 / 6





*** Capability 5 deg/sec and 10 deg/sec^2**

IPSRU Measured Error Allocation
(Using Gyro S/N 266, Y-Axis)

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Jitter Performance Measurement

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Base Motion Isolation Transfer Function

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Precision Pointing Test Facility

- Quiet Reference Base for Mounting Scoring Sensors
  - 9000 lb. granite block on 150,000 lb. vibration isolated concrete pier
  - <9 nrad rms, 0.1 - 300 Hz
- Low Noise Sensors (custom developed at Draper)
  - Enhanced Angle Sensor (quad-type) measures angle of IPSRU beam
    - <2 nrad rms, 0.1 - 300 Hz
  - Enhanced Resolution Laser Interferometer measures angle of platform
    - 6.8 nrad/bit, +/- 2 degree range - dynamic range: 5×10^{6}
- Real-Time Performance Testing
  - Vehicle Simulator (Three-Axis Rate Table) applied base disturbance to IPSRU and performed follow-up function for large angle maneuvers
  - Vacuum/thermal chamber simulated satellite dynamic disturbance environment
- Data Acquisition System
  - High bandwidth LOS data and attitude determination data

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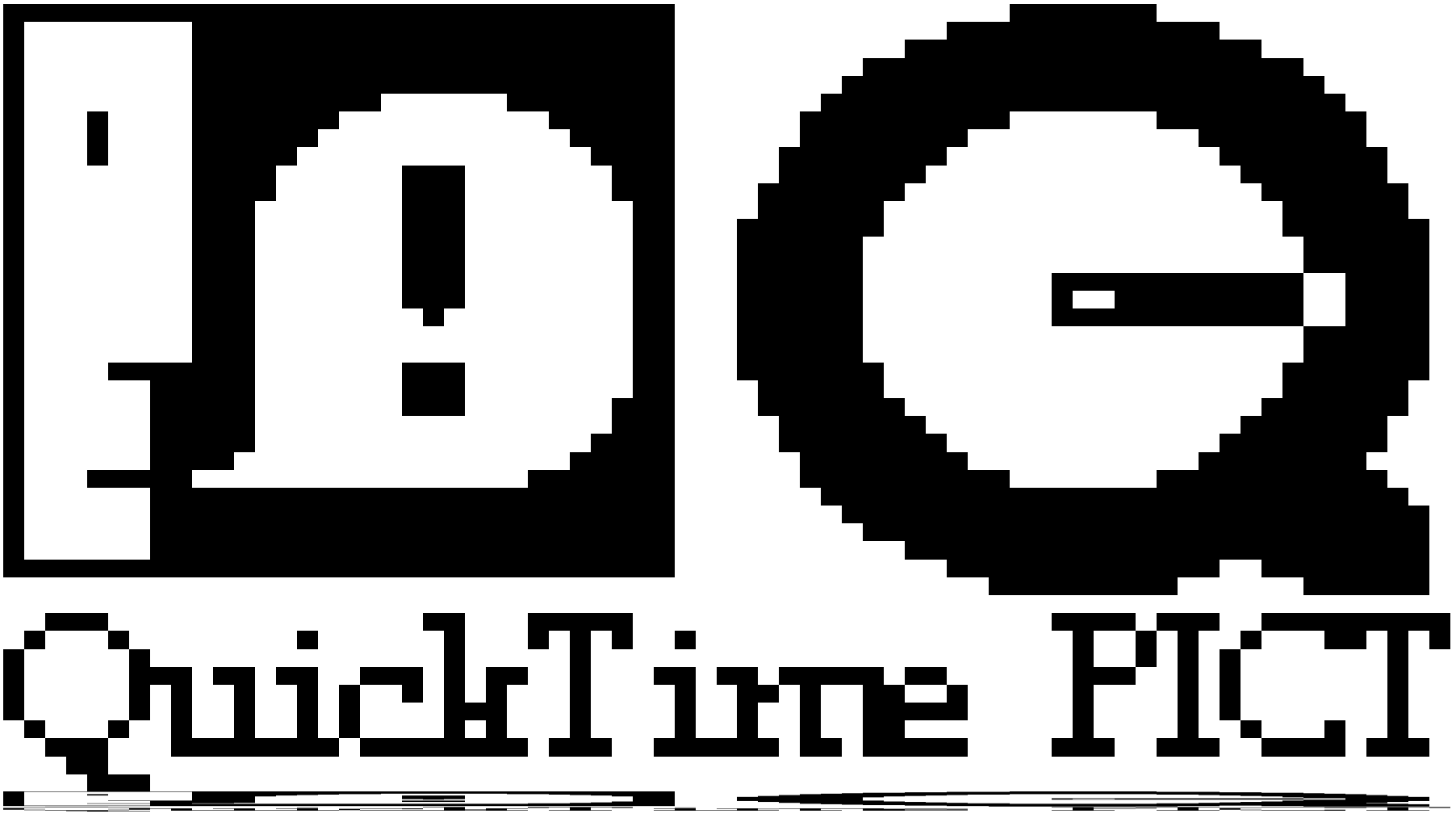
IPSRU System Test Configuration



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Integrated Test Facility Layout

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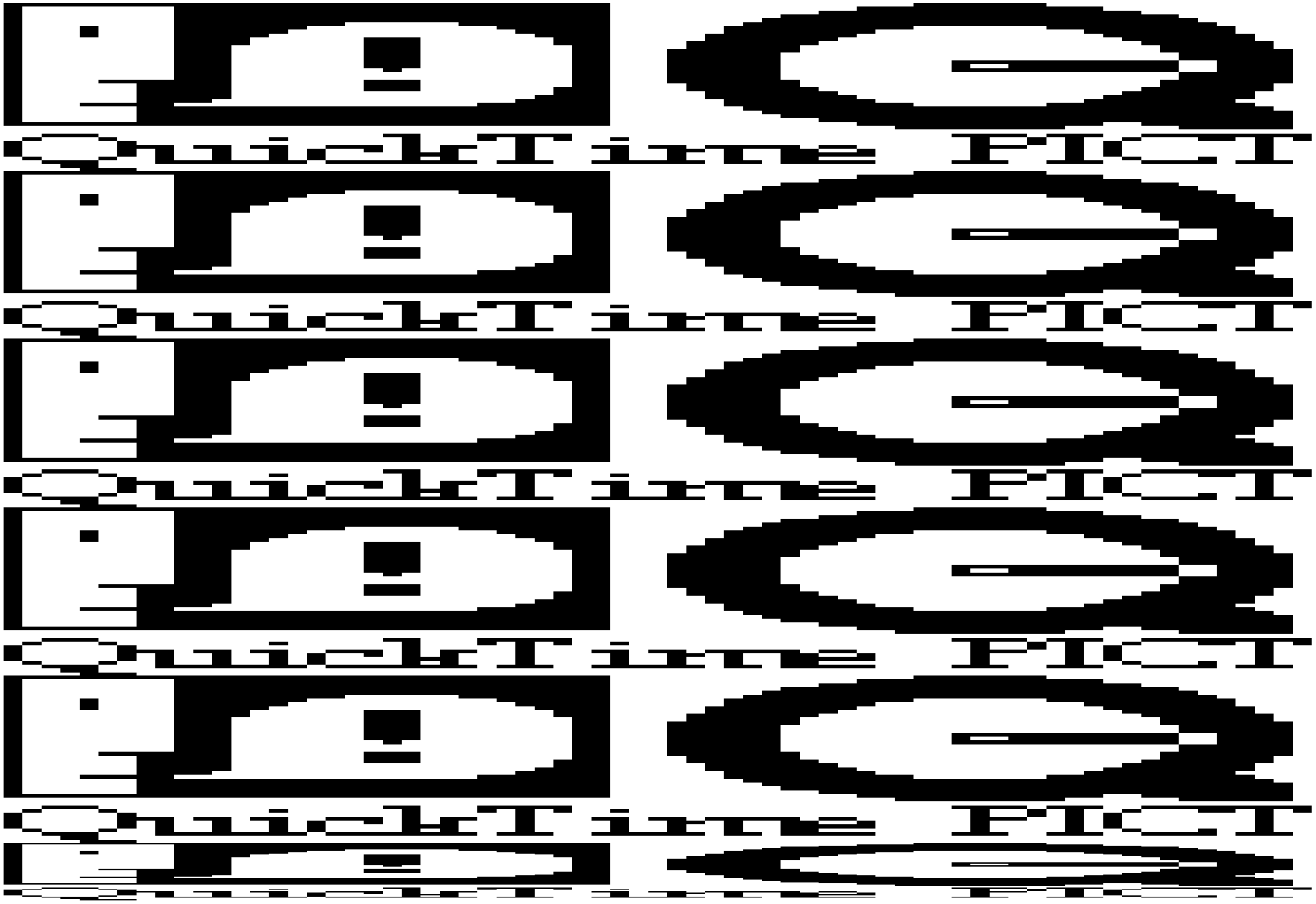
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Angle Sensor Test Verification

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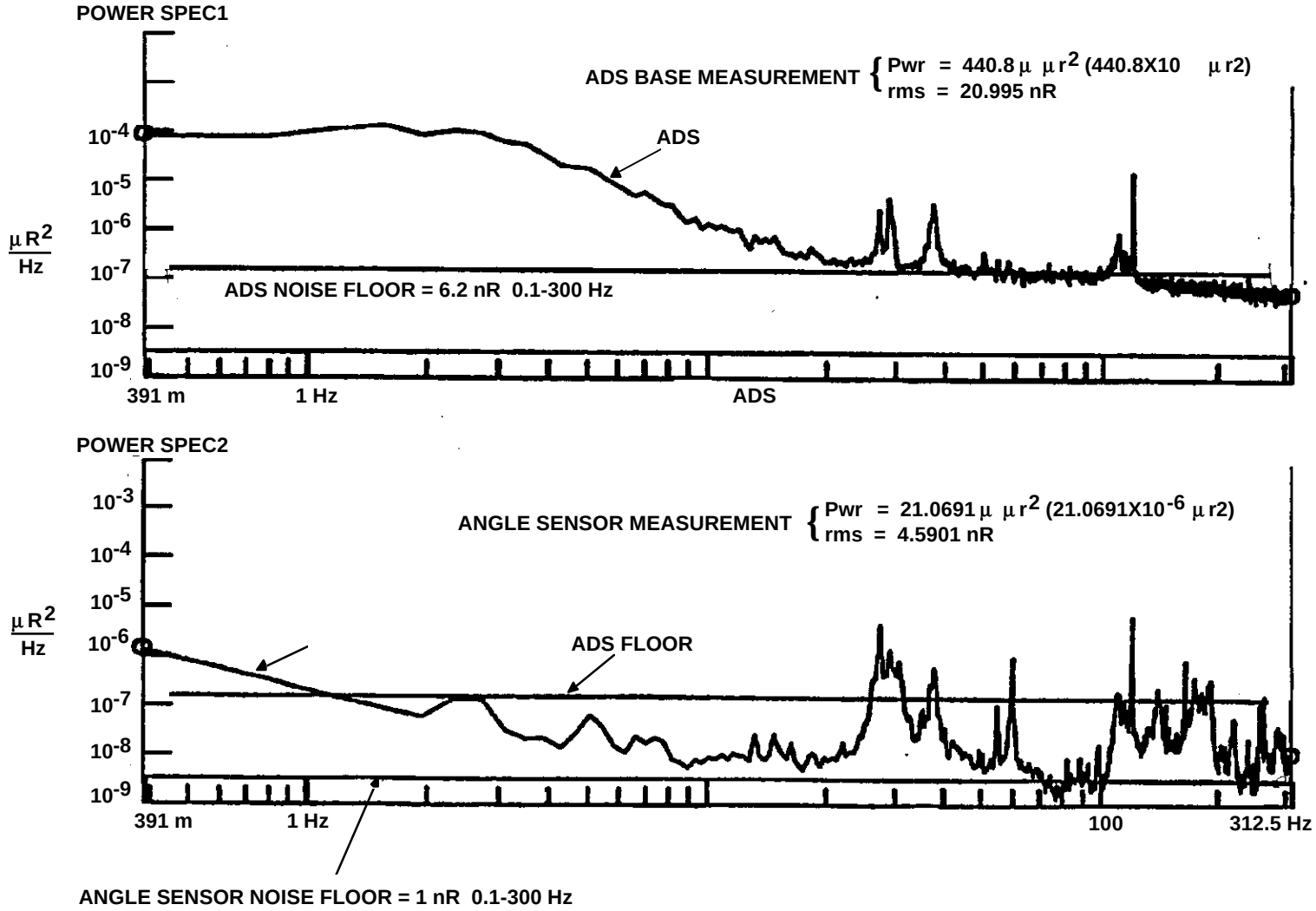
Angle Sensor Measurement Performance



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Enhanced IPSRU

- In response to an SMC inquiry Draper Laboratory has investigated the possibility of achieving 5 nRad, 0.1-300 Hz jitter performance
- The primary jitter performance limitation has been the Gyroscope(1) (noise& bandwidth of the DTG, wheel speed)
  - 28 nRad rms 0.1-100Hz, wheel speed -240 rps
- An enhanced higher performance IPSRU can be realized:
  - Use of Draper low noise third generation gyro(2)
    - 1.8 nRad Rms, 0.1-100 Hz, wheel speed-800 rps
  - Draper's interferometric high performance fiber optic gyroscope is also being assessed as a candidate
  - Higher gyro bandwidth enables wider band platform servo with increased base motion rejection
  - ADS may not be required

(1) Delivered IPSRU required an ADS implementation & composite filter.
(2) Gas Bearing gyro mechanical noise is insignificant.

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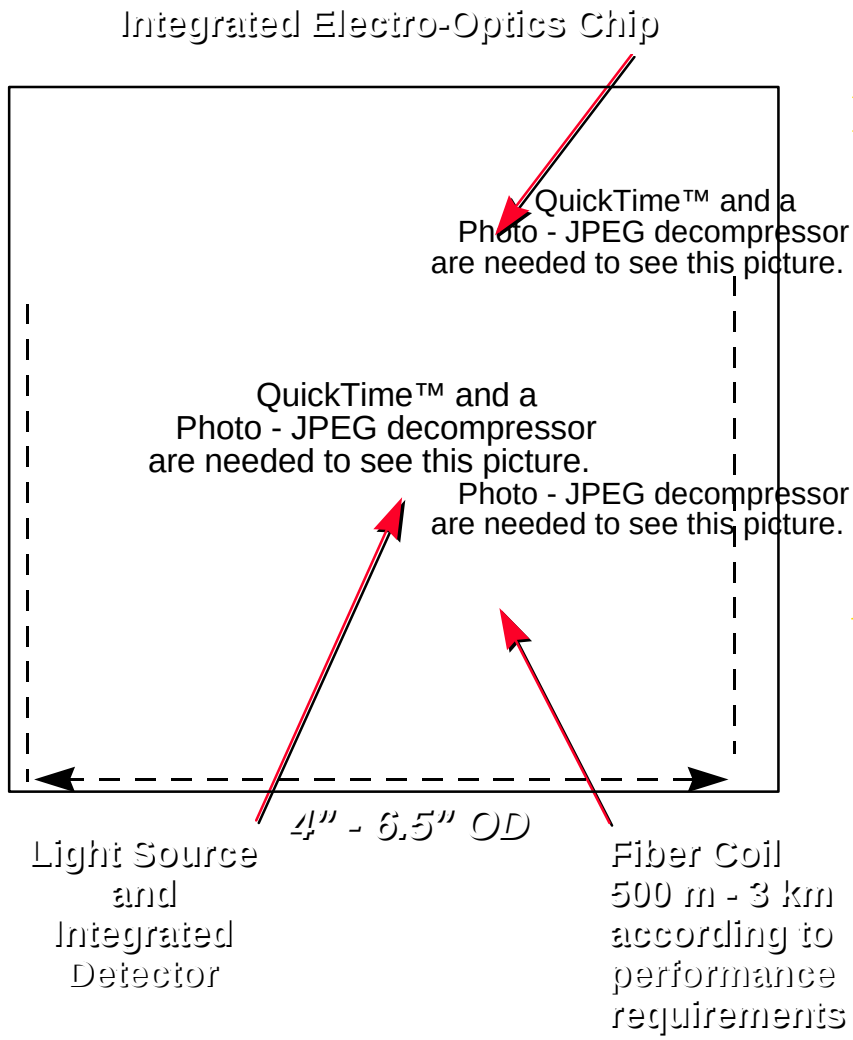
Interferometric Fiber-Optic Gyroscope (IFOG)

Closed-loop optical gyroscopes for precise angular rate sensing



Demonstrated Performance (2.8-km optical fiber)

- Bias stability:
  - 4.2×10^{-4} deg/hr
- Angle random walk:
  - 2.3×10^{-4} deg/ $\sqrt{\text{hr}}$
- Scale factor stability: <1 ppm

Applications

- Strategic missile
- Submarine navigation
- Satellite attitude determination and pointing

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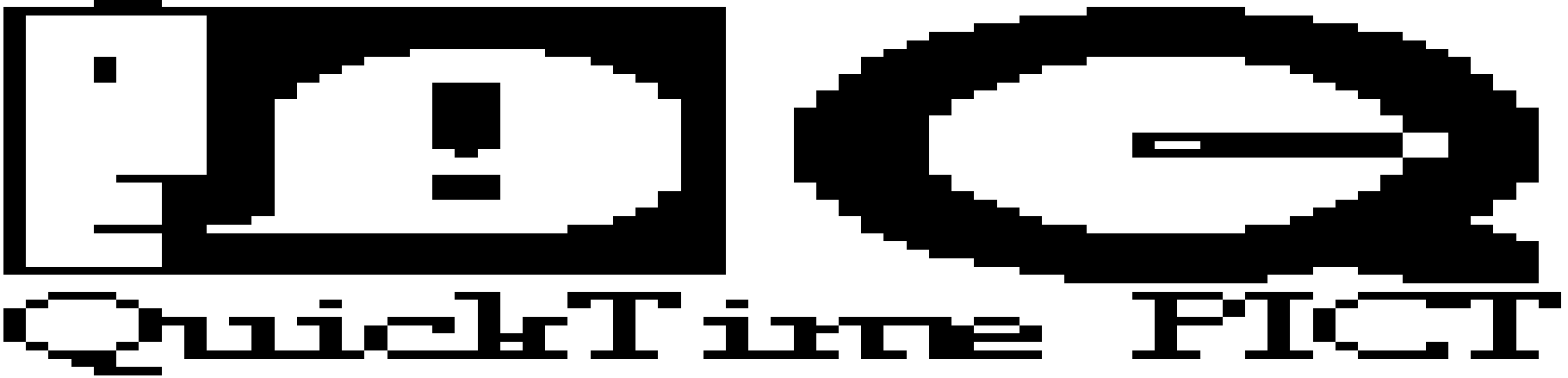
QuickTime PICT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Low Noise Third Generation Gyro History/Reliability

- Low Noise Third Generation Gyro (LNTGG) is a derivative of Draper's Third Generation Gyro (TGG) which flew on MIT Lincoln Laboratory Experimental Satellites (LES-8 and 9) and is in Peacekeeper IMUs
  - LNTGG noise reduction has been realized via the development of an ultra low noise signal generator
- LES-8 gyro package accumulated over 40,000 hours prior to being deactivated in 1983
  - It was reactivated after 7 years at -36°F and operated successfully (no change in performance) for five months before being deactivated
- Peacekeeper production TGGs since 1993 have accumulated 8.4 million silo hours* producing an MTBF = 310,000 hours. (Several units have in excess of 51,000 hours of continuous operation)
- Radiation capabilities exceed space environment requirements

*** As of December '97**

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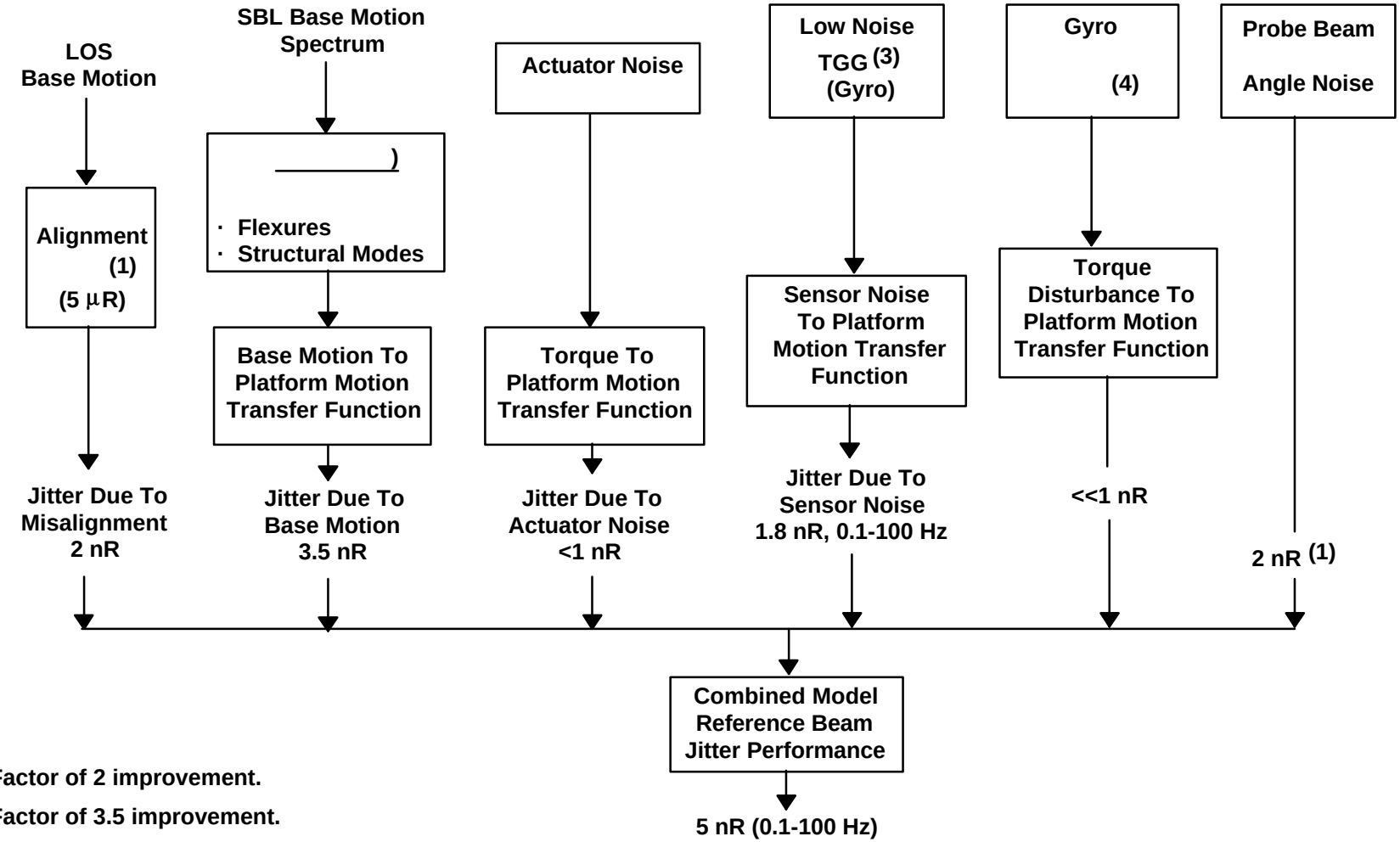
High Precision IPSRU Projections Using Low Noise - 4th Generation TGG



(1) Factor of 2 improvement.

(2) Factor of 3.5 improvement.

(3) ADS not required, LNTGG test data.

(4) Gas bearing and floated, mechanical noise << 1 nRad.

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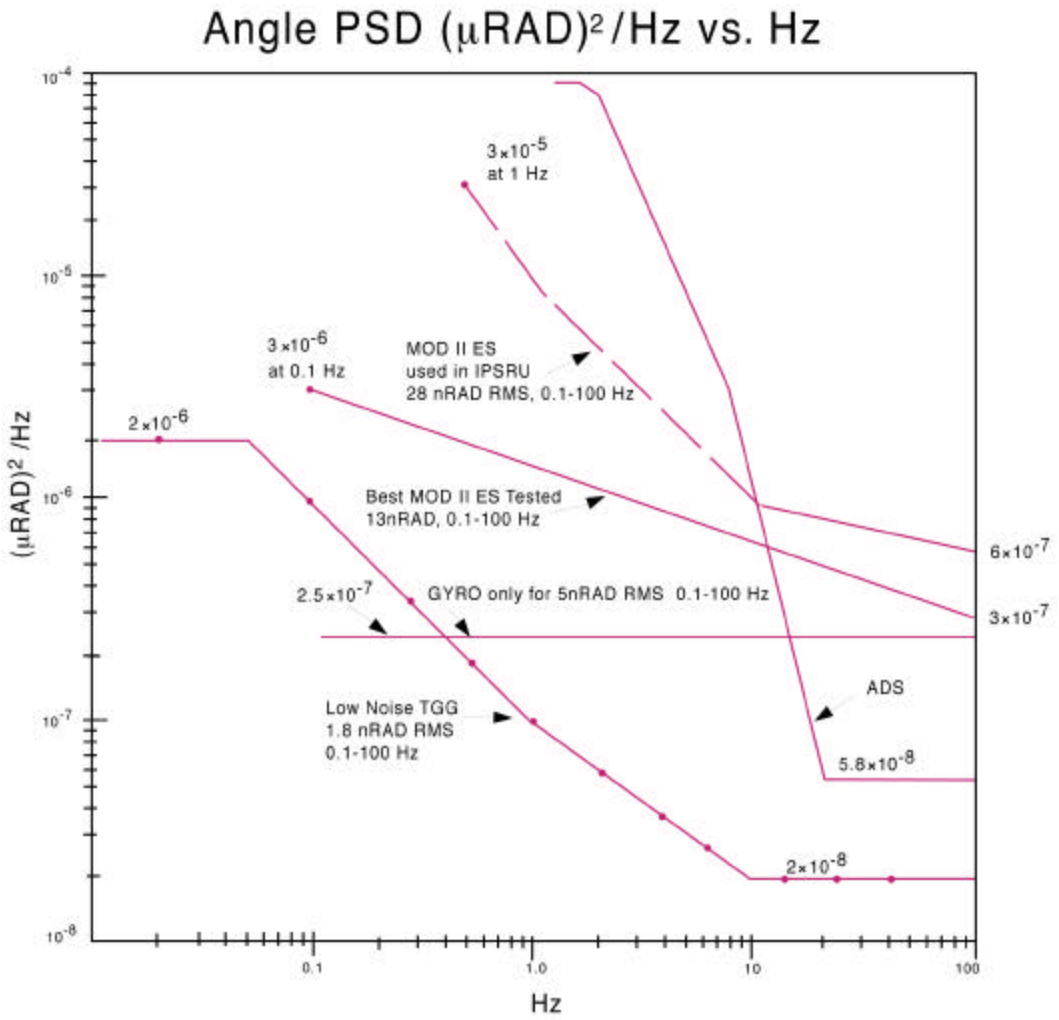
Angle PSD (μRad)² /HZ vs Hz



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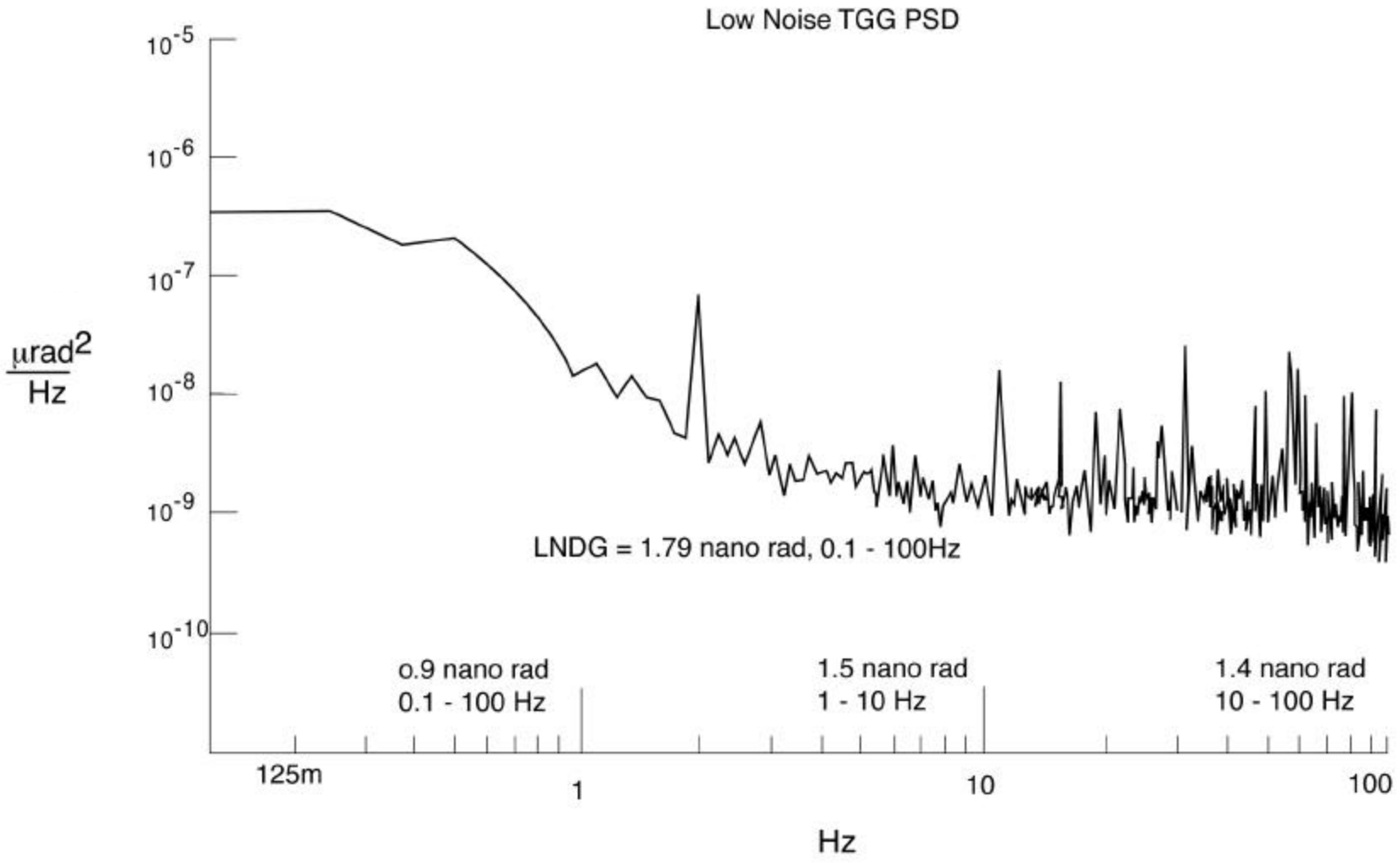
Low Noise TGG PSD



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Conclusion

- Draper has a broad range of technologies, tools, and expertise applicable to the SBLRD
  - IPSRU is a unique, self-contained system that has demonstrated precision pointing, LOS jitter elimination, and attitude reference performance levels required for the SBLRD
  - Draper has also developed several other stabilization and alignment reference concepts with both higher and lower cost/performance goals
  - Draper has unique inertial precision pointing and jitter evaluation system test capabilities
  - Draper has a broad range of integrated optical and structural control system design and test capabilities
- Draper's expertise is available to both the Air Force and the SBLRD prime contractors on a non-exclusive basis
  - Non-Disclosure Agreements will protect proprietary data

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